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Design and optimization of the dies for the isothermal forging of a cam

D. Salcedo^{a,*}, C.J. Luis^a, R. Luri^a, J. León^a, I. Puertas^a, J.P. Fuentes^a

^a *Mechanical, Energetics and Materials Engineering Department, Public University of Navarre, Campus de Arrosadia, s/n, 31006, Pamplona, Spain,*

Abstract

In the present study, the design of the dies required for the isothermal forging of a cam is analysed by finite volume method. Specifically, cams are of great importance in automotive industry, where a lower weight and an improvement in the lubrication or in the materials to be in contact lead to a significant reduction in the fuel cost.

The flow stress curves of one Al-Mg alloy were firstly determined by using compression tests. Once these flow stress curves were obtained, FV simulation was employed. In the forging process, the optimum die configuration has been selected. To this end, several aspects have been taken into account such as the force required for the forging, the correct die filling, the introduced plastic strain and the damage imparted to the billet.

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1. Introduction

The isothermal forging is a manufacturing process with which an improvement in the mechanical properties of the material processed is allowed to be obtained due to the strain introduced and to the better control of the temperature during the process. With the temperature control, a material with little grain growth may be achieved thus avoiding a decrease in the mechanical properties [1].

* Corresponding author. Tel.: +34-948169608; fax: +34-948169099.
E-mail address: daniel.salcedo@unavarra.es

On the other hand, the so-called Severe Plastic Deformation (SPD) processes introduce high plastic strain values to the materials processed. These materials exhibit very interesting properties such as better mechanical strength, yielding strength and fatigue behaviour, but reducing their elongation at break [2,3]. Moreover, the design optimization of the dies used for the forging may also help to optimize the mechanical properties obtained [4-8].

In this present research work, forging dies are to be pre-designed in order to manufacture cams by using different configurations. The material employed is AA5754. This mechanical component is usually manufactured by the machining process of steels which are subsequently subjected to a quenching heat treatment. The possibility of applying isothermally forged aluminium to the manufacturing of cams would improve the total weight as well as their corrosion behaviour.

Cams are very widespread mechanical components used for different mechanisms as they allow precise movements to be allowed with the help of a follower from a rotational movement. They are usually employed in common explosion engines, specifically in the automotive sector [9]. The surface quality has a great deal of importance in this case as well as the existing lubrication in order to reduce the cam wear [10,11]. Different materials and surface thermal treatments have been researched in order to improve the wear behaviour during the life of this mechanical component [12].

For this reason, it is considered that the application of lighter materials than those commonly used along with a noticeable improvement in their mechanical properties, as it is the case of the aluminium alloys, involves a very interesting technological advance for such a widespread mechanical element.

2. Methodology

In this section, the methodology employed to carry out the simulations will be shown. Firstly, different isothermal compression tests were carried out from billets taken from the material previously mentioned.

3-D FV simulations of isothermal forging of cams are carried out in different configurations: forging with one or two strokes, different initial placing for the preform, different preform geometries, among others. In order to obtain a better flow of the material and lower forging forces, different geometries of the dies have been employed. Finally, several aspects such as the imparted damage, the accumulated strain, the forging force and the correct die filling are studied in order to select the most adequate configuration.

For all the simulations a Shear friction model and a friction coefficient of 0.3 have been used in all the simulations. The process definition selected was a forming with flash process and the press was a hydraulic press. The press forging velocity was considered to be 1 mm/s.

Heat generation and heat transfer to environment, conduction to the dies were considered in all the simulations. An initial temperature of 20 °C and a heat transfer coefficient to environment (HTC) variable with temperature were selected. The heat transfer coefficient to the part was also considered to be variable with temperature and it was dependent on the contact force and on the material yielding strength. Heat generation by deformation fraction of 0.9 was selected.

The FV simulations were performed using a SIsurface-Mesher to mesh the part boundary with 1 mm edge mesh for the part with a minimum edge size of 0.25 mm with a volume mesh of 1 mm. When in one of the configurations, two forging stages are needed, the mesh of the first stroke has to be saved, including stress, strain, damage, etc. and it has to be used as the part to be forged in the second stroke. The simulations have been performed with the simufact.forming 12.0 software. The Dytran Rieman solver has been employed and the calculations have been carried out using two processors in parallel.

Lastly, two significant limitations in the design have to be considered in relation to the experimental tests. These are as follows: a maximum press force of 3000 kN and the geometry of the starting billet. This preform has to have maximum values of diameter and length of 18 mm and 80 mm, respectively, although its length was finally limited to a maximum value of 54 mm because of buckling problems. Fig. 1 shows the initial preform and the cam geometries that are wanted to be obtained. The draft angle and the fillet radii were taken as 20° and 3 mm, respectively, in all cases.

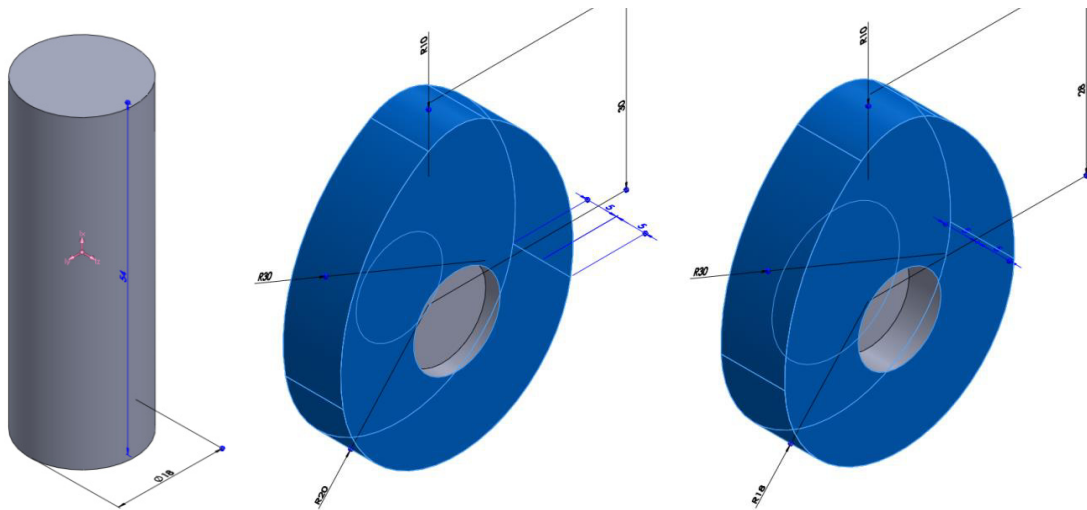


Fig. 1. Geometry of the preform and the final cams forged

The different configurations studied in this present research work are shown below.

2.1. One stroke configurations

Fig. 2 shows the configurations for the one stroke forging process. In case (a), the dies are completely symmetric. In case (b) the bottom die allows a precise position of the preform and the upper die has a punch nose shape in order to start the hole through which would be attached to the shaft. Finally, case (c) is similar to previous case but with a slight decrease in the size of the cavity for the cam to be forged.

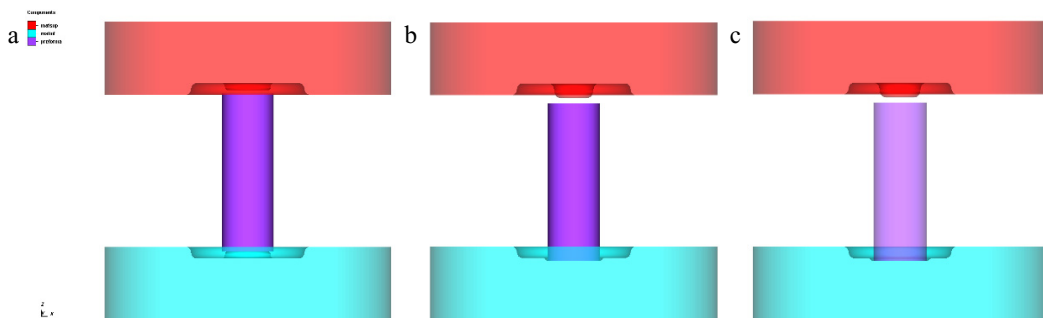


Fig. 2. Die geometries for the one stroke configurations

2.2. Two strokes configurations

Fig. 3 shows the different configurations for the preform forging when two strokes are needed in order to carry out the cam forging process. In case (a) both forging dies are symmetric and the preform is axisymmetric. In case (b) the forging dies are symmetric but the preform is not axisymmetric, where its shape is closer to the final cam shape. Finally, in case (c) the dies are symmetric and the preform is axisymmetric but with a lower thickness value so that it may adapt to the totally different die geometry in the case of the second stroke.

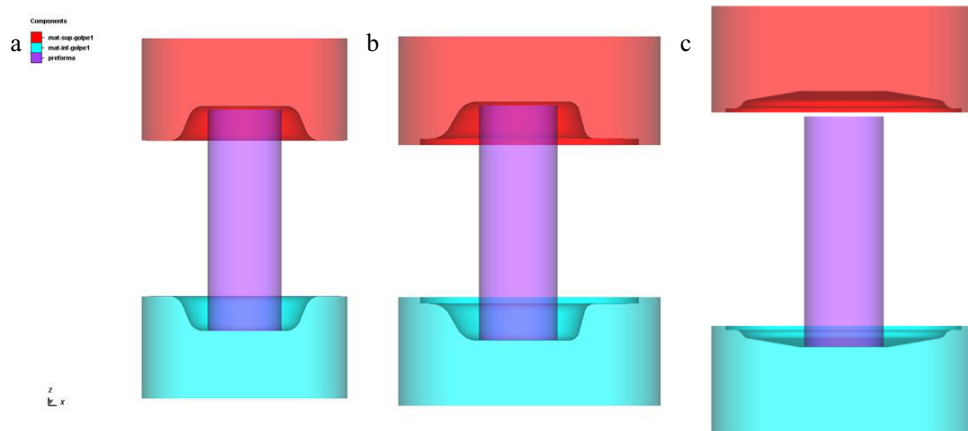


Fig. 3. Die geometries for the two stroke configurations

Fig. 4 shows the die configurations in the case of the second forging stroke. In cases (a) and (b), the bottom die allows to position the preform precisely and the upper one has a punch nose shape so as to start the hole through which is attached to the shaft. It has a slight decrease in the size of the cavity of the cam to be forged. The geometry is similar to case (c) with one stroke but in this case, preforms from previously shown cases (a) and (b) are used. Lastly, case (c) consists in a configuration totally different from the previous ones. The forging dies are symmetric but the cavity is vertically designed. The bottom die allows the precise position of the preform due to its geometry and the hole through which is attached to the shaft is not considered.

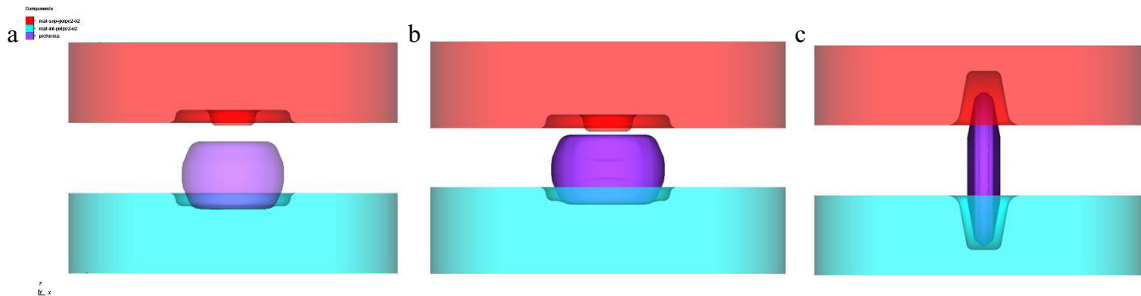


Fig. 4. Die geometries of the configurations for the second stroke

Hereafter, the different configurations will be named as one stroke or two stroke (preform and final shape) followed by the letter assigned in the previous figures: (a), (b) and (c).

3. Results and discussion

Within the results obtained from the simulations, this research work is centred on the maximum plastic strain and its homogeneity inside the material as well as the maximum damage imparted to the material during the forging process following the Cockcroft-Latham's model. Moreover, the force required for the isothermal cam forging at room temperature is taken into account along with the correct filling of the die cavity. Table 1 shows a summary with the results obtained for all the cases under consideration.

Table 1. Results obtained in all the study cases

Sample	Plastic strain	Damage	Force (kN)
One stroke (a)	2.921	0.520	750
One stroke (b)	3.035	0.532	720
One stroke (c)	3.005	0.483	1750
Two strokes, preform (a)	0.931	0.281	485
Two strokes, preform (b)	1.174	0.315	260
Two strokes, preform (c)	1.566	0.493	1250
Two strokes, final shape (a)	2.981	0.398	1925
Two strokes, final shape (b)	3.009	0.447	1900
Two strokes, final shape (c)	3.204	0.492	180

3.1. Accumulated plastic strain

The higher the amount of accumulated plastic strain is, the higher the cam hardness is. Moreover, the more homogeneous this plastic strain value is, the more homogeneous the mechanical properties of the mechanical component to be forged are.

In the case of the one stroke configurations, maximum plastic strain values for cases (b) and (c) are observed at the zone of the punch nose shape. Fig. 5 shows that at the cam surface effective zone, the strain value is not very homogeneous and it is similar in all the cases under consideration. It is observed that for case (b), this strain value is lower as the die cavity is not completely filled.

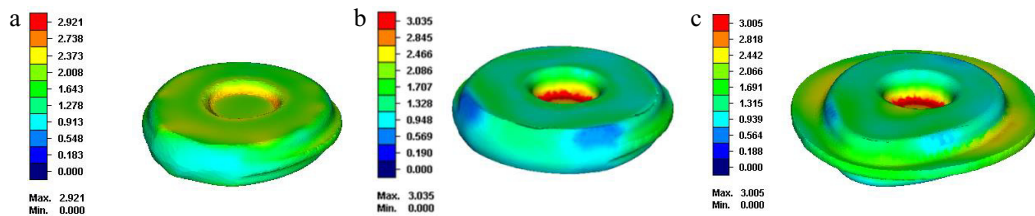


Fig. 5. Plastic strain for the one stroke configurations

The strain values for the preforms can be observed in Fig. 6, where the maximum plastic strain value takes place in case (c). This is caused due to its smaller thickness for the same initial billet, thus obtaining a much higher reduction than in the other cases. Cases (a) and (b) are very similar, where the maximum strain value is achieved at the medium zone of the preform although the homogeneity observed is much better in case (b).

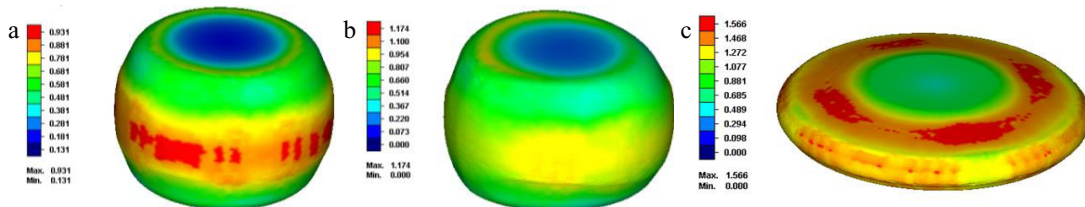


Fig. 6. Preform plastic strain for the different configurations

Fig. 7 shows the final shape obtained after the forging second stroke. Cases (a) and (b) are very similar and the maximum strain value happens at the die punch zone. Moreover, a better homogeneity is achieved rather than in one

stroke case (b). Case (c) does not manage to fill the die completely and in spite of this, the strain value is the highest for all the study cases.

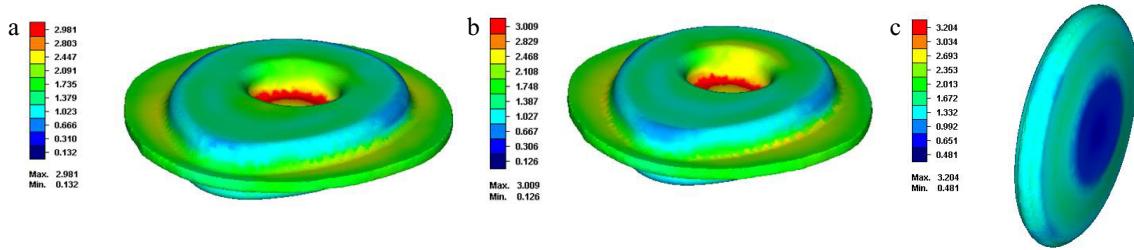


Fig. 7. Plastic strain of the configurations for the second stroke

3.2. Imparted damage

The damage predicted by Cokroft-Latham's model is a variable which estimates the probability for the cracks to appear and it is not dependant on the material modelled with the flow rules in the finite volume simulations. Therefore, this parameter is intended to be minimised as the appearance of cracks in the forged mechanical component will lead to its withdrawal and to its non-usage anymore.

In the case of the one stroke configurations, it may be observed that the maximum damage takes place in the cam flash. Fig. 8 shows the study cases. In case (a) the damage is higher in all the cam surface, which would cause additional problems when it is used in an engine. In cases (b) and (c), the distribution of the damage value is similar, the maximum being reached at 0°, 90°, 180° and 270° along the work surface. In all cases for one stroke, the damage turns out to be too high.

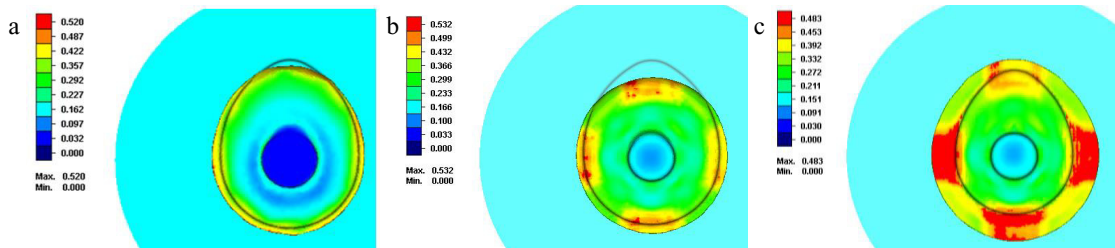


Fig. 8. Damage value for the one stroke configurations

Fig. 9 shows the case for the preforms, in which the maximum damage value takes place in case (c). Cases (a) and (b) are very similar, where the maximum damage is reached at the preform medium zone although it is slightly higher for (b) configuration.

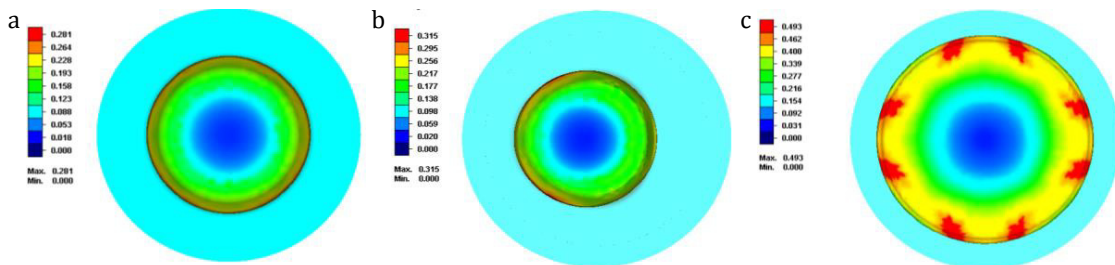


Fig. 9. Damage value of the different configurations for the preform

Fig. 10 shows the final shape obtained after the forging second stroke. The optimum case turns out to be (a), followed by case (b), where the values obtained are lower than those obtained from one stroke configurations. (c) configuration does not manage to fill the die completely and in spite of this, the damage reaches its maximum value considering all the cases with two stroke forging.

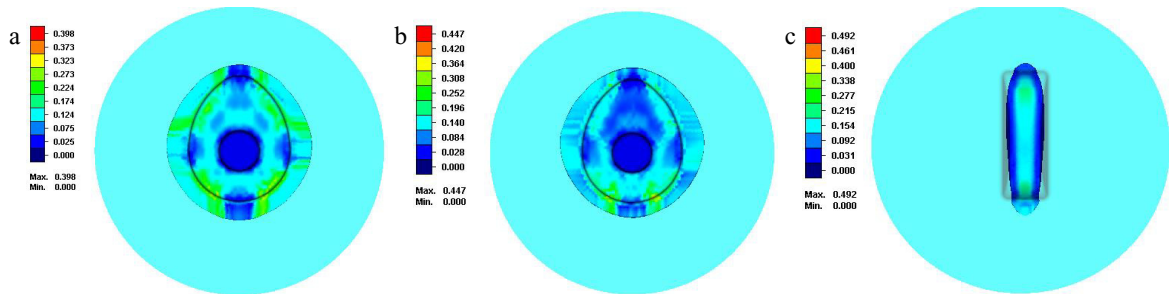


Fig. 10. Damage value of the different configurations for the second stroke

3.3. Force required and die filling

The force required for the forging process is a key factor as it determines the equipment capacity which is necessary to carry out the process. In this case, the maximum force value which must not be exceeded is 3000 kN. As in any of the studied configurations, this value is not surpassed, the analysis of this variable is considered to be correct.

Nevertheless, another fundamental requirement is the complete filling of the die cavity. In this present study, the configurations which fulfil this restriction are as follows: one stroke (c), two strokes with final shape (a) and two strokes with final shape (b). For this reason, the rest of the configurations studied are discarded.

4. Conclusions

This present study deals with the design of different die configurations for the isothermal forging of cams. Six different configurations are studied, three which consist of a single stroke forging and another three which consist of a two stroke forging.

The aim is to determine the most adequate configuration, which turns out to be a compromise between several aspects such as maximum accumulated plastic strain, complete die filling, minimum imparted damage and minimum required forging force.

Starting from this, the following configurations are considered to fulfil the design requirements: one stroke (c), two strokes with final shape (a) and two strokes with final shape (b). The configuration with the best achieved results is two strokes with final shape (a), in which the maximum strain value is 2.981, the maximum damage is 0.398 and the forging force is 1925 kN. In addition, the die filling is complete and the strain homogeneity is better than in the one stroke forging configurations.

Finally, the optimization of this configuration using the Design of Experiments (DOE) technique is left for a future research work, where draft angle, fillet radius and flash thickness may be considered as design factors. The manufacturing of the set of dies designed as well as the experimental forging tests are also left for a future research study.

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References

- [1] T. Altan, G. Ngaile, G. Shen, Cold and hot forging: Fundamentals and applications, first ed., ASM International, USA, 2005.
- [2] R.Z. Valiev, T.G. Langdon, Principles of equal-channel angular pressing as a processing tool for grain refinement, *Progress in Mat. Sci.* 51 (2006) 881-981.
- [3] V.M. Segal, V.I. Reznikov, A.E. Drobysheskiy, V.I. Kopylov, Plastic working of metals by simple shear. *Russ. Metall.* 99 (1981) 99-105.
- [4] D. Salcedo, C. J. Luis-Pérez, J. León, R. Luri and I. Puertas, A Method for Obtaining Spur Gears from Nanostructured Materials, *Ad. Mater. Res.* 498 (2012) 7-12.
- [5] V. Vazquez, T. Altan, Die design for flashless forging of complex parts, *J. Mater. Process. Technol.* 98 (2000) 81-89.
- [6] H. Grass, C. Krempaszky, E. Werner, 3-D FEM-simulation of hot forming processes for the production of a connecting rod, *Comput. Mater. Sci.* 36 (2006) 480-489.
- [7] Y. Zhang, D. Shan, F. Xu, Flow lines control of disk structure with complex shape in isothermal precision forging, *J. Mater. Process. Technol.* 209 (2009) 745-753.
- [8] I. Puertas, C.J. Luis Pérez, D. Salcedo, J. León, J.P. Fuertes, R. Luri, Design and mechanical property analysis of AA1050 turbine blades manufactured by equal channel angular extrusion and isothermal forging, *Mater. Des.* 52 (2013) 774-784.
- [9] M. Priest and C.M. Taylor, Automobile engine tribology-approaching the surface, *Wear* 241 (2000) 193-203.
- [10] P. Lindholm, S. Björklund and M. Calvo, Characterisation of wear on a cam follower system in a diesel engine, *Wear* 254 (2003) 1199-1207.
- [11] S.D.A. Lawes, S.V. Hainsworth, M.E. Fitzpatrick, Impact wear testing of diamond-like carbon films for engine valve-tappet surfaces, *Wear* 268 (2010) 1303-1308.
- [12] M.B. Karamis, A. Alper, B. Selc-uk and F. Nair, The effects of different ceramics size and volume fraction on wear behavior of Al matrix composites (for automobile cam material), *Wear* 289 (2012) 73-81.